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MULTIPLE JET AIR COOLING RELATING WITH REYNOLDS NUMBER AND NUSSELT NUMBER

Dr. NIRANJAN MURTHY

Associate Professor, Department of Mechanical Engineering, M. S. Ramaiah Institute of Technology, Bangalore, Karnataka, India

ABSTRACT

The present study is a multiple air jet cooling. In the present research work, the tests data of cooling abilities of air jets were reported. The test surface considered is made up of copper. It is selected because of its higher thermal conductivity. The vertical and horizontal jets of each 0.025 cm and 0.05 cm were tested. These jets are organized in an array of 7 x 7 square type with jet spacing of 3 mm. The Reynolds number ranges between 1,200 and 4,500 were considered for this investigation. The heat flux has varied from 25 to 250 W/m^2. A non-dimensional relationship is established in this study for both jets of 0.05 cm and 0.025 cm diameter. It is to be noted that heat flux is a strong function on Nusselt number and other parameters, such as Reynolds number. Distance between the test plate and nozzle exits were insignificant.

KEYWORDS: Multiple Air Cooling, Heat Transfer Augmentation & Vertical and Horizontal Jets

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Original Article

1. INTRODUCTION

There are so many conventional and non-conventional techniques available to remove heat from the surface in a faster manner. Indisputably, the multiple jet air cooling is a good heat removal technique compared to other conventional methods of heat flux removals. Today, the size and speed of the electronic components are reduced, which requires a better and a good method to remove the heat in a faster manner as compared to other old techniques, though the heat transfer in a multiple air jet cooling is a complex phenomenon to understand. So, many studies revealed that the multiple jet impingement cooling is a very good method for heat removal. This multiple jet air cooling is one of the most effective methods to solve today's problem of high heat removal in a faster rate.

2. LITERATURE REVIEW

Zhang, L., Koo, J. M., Goodson, K. E., Kenny, T. W., Maveety J. G., Sanchez, E. A., Wang E. N. [1] They used heat sinks for cooling of VLSI chips. The better temperature consistency is obtained at the hot places with micro-jet heat sinks. They compared the performance of micro jets and micro-channels. The results revealed that micro jets have a better thermal uniformity as compared to micro-channels. They also observed that micro jets are considerably more stable and do not cause superheating. The above advantages will lead to micro jets that are more preferred for effective cooling.

Fabbri, M., Jiang, S. and Dhir, V. K. [2]. They tested a single circular jet of different diameters varying from 250 µm to 50 µm. They have chosen the spacing between the holes as 1, 2 and 3 mm. The working fluids used in these investigations were water and FC-40. The Prandtl numbers were varied from 8 to 78 and a Reynolds number in the range of 90 to 2000 with water as a working fluid. They noted that the water is capable of removing

high heat flux density as high as 250 W/m^2. The results revealed that Nusselt number strongly depends on Reynolds number for all values of heat fluxes.

Two-phase jet impingement cooling has also been studied by Yang Shang, Andrew A. O. Tay and Xue Hong [3]. The resistor of 2 and 3 mm thick were used as a test surface. The jet velocity effect and sub-cooling effects were considered. Results revealed that with a single-phase boiling heat transfer, the high-heat transfer co-efficient were found with high jet velocities. The jet diameter effect is negligible on the heat transfer.

B. Donnelly, T. S. O'Donovan, D. B. and Murray, C. Kinsella, [4]. They conducted test on a swirl jet. It mostly increases the heat transfer from a tested surface in a radially unchanging manner. The degree of swirl is 0 to 2.25^0/mm and the distance from jet exit to test surface is in the range 0.5 to 0.6. The Reynolds number varies from 10,000 to 30,000. They noted that overall heat transfer increases when swirl generator increases. It may be due to the turbulence which has a more direct impact on heat transfer than the swirl motion of the flow. They observed that the surface heat transfer is decreased in the zone of stagnation due to the swirl creating the blockage of flow. They observed that the ideal degree of swirl from a heat transfer is a function of distance between nozzle exit to the test surface.

3. TERMINOLOGY

A	Test plate surface area
d	Diameter of jet
h	Heat transfer coefficient
k	Thermal conductivity
Nu	Nusselt number
P	heat transfer sum
q	Heat flux
Q	Total discharge
R_e	Reynolds number
T_b	Air temperature (^{0}C)
T_c	Test plate temperature (^{0}C)
T_a	Inlet air temperature (^{0}C)
V	Jet speed
ν	Kinematic viscosity
Z	Nozzle height from test surface
ΔT	Difference in temperature between the test surface and inlet air

4. EXPERIMENTAL SET UP AND TEST METHODS

The construction and assembly of the test module is revealed in figure 1. The apparatus is designed in such a way that it can be suitable to carry out both vertical and horizontal jets in the same test assembly. The test material selected for this investigation is copper, which is chosen because of its higher thermal conductivity and this test plate, which is made up of copper is heated by using the heating coil. The size of this plate is 1 mm thick with 2 x 2 cm in size. The two thermocouples are placed in the central line of this plate to get the good uniformity of surface temperature. The entire test apparatus is well insulated by using a Teflon bracket.

A transformer is used to vary the heat input and digital temperature indicators reveal the surface temperature of the plate. It is adjusted in such a way that if it exceeds preset values, it will automatically cut off. Venturimeter is used to find out the air flow rate. The jets used in the present investigations were laser drilled with the diameter of 0.025 and 0.05 cm, arranged in a 7 x 7 array with a spacing of 3 mm between the jets. The height between jet exit to the hot plate surface is kept in the range of 1 to 2cm.

Before conducting the experiments, the test surface is prepared to remove any dust or sediments, which are present in the plate. The power input, air flow rate and the distance between the test surface to jet exit are changed during the experiments. When the test surface is reached, a steady state condition of the data were recorded for calculation purposes. The test was conducted for all types of horizontal and vertical jets.

Below list reveals the parameters considered in this study.

- Diameter of jets = 0.025 cm, 0.05 cm
- Heat flux = 25 to 200 W/cm^2
- Reynolds number = 1300 to 4500
- Test surface to jet exit distance = 1 cm, 2 cm
- Vertical and horizontal jets

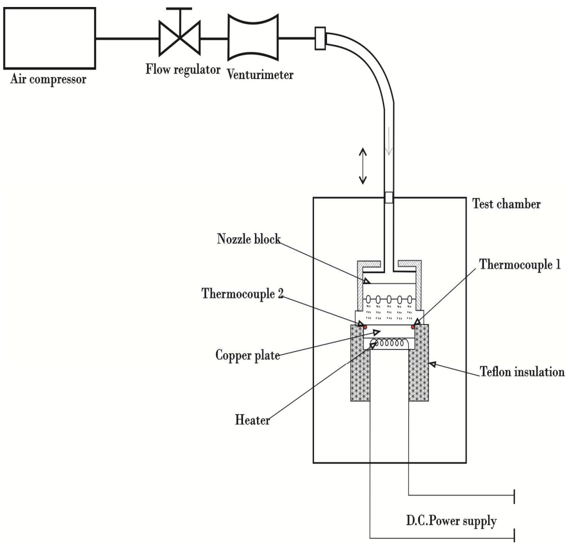

Figure 1: Schematic Diagram for Multiple Jet Air Cooling.

4.1 Data Reduction

The heat flux is determined by the following equation:

q = P/A, where P = Heat input and A = Area of test surface

The heat transfer coefficient [h] is calculated from the below relation

h = q/Δt, where q = heat flux and

Δt = Temperature difference between the test surface and jet exit

The Reynolds number is evaluated by the relation

$Re = \rho V\, d/\mu$

where ρ = Density of fluid, V = Jet velocity and μ = Dynamic viscosity

The non-dimensional Nusselt number is determined by the following relation:

Nu = hd/k, where h = heat transfer coefficient

K = Thermal conductivity and d = Diameter of jet

The plate surface temperatures are measured by using the thermocouples embedded within the test plate at two places. The accuracy of these thermocouples is within 2^0C. The material chosen for the test plate is copper. Copper is considered meanwhile it is having more thermal conductivity properties.

For the calculation purposes, the total heat dissipated to the entire area of the plate is considered. The heat transfer rate that is the heat input is not constant but it slightly varies from point to point in the test surface. This non-uniformity is very less, so it can be neglected.

Table 1: Heat Loss Estimation

Sl. No.	Power Input in W	Conduction Heat Loss in W	Radiation Heat Loss in W	Conduction Heat Loss in %	Radiation Heat Loss in %	Total Loss in %
1	800	1.6	0.135	0.2	0.017	0.217
2	500	1.44	0.068	0.288	0.0137	0.30
3	400	1.28	0.053	0.32	0.0132	0.332
4	200	0.48	0.038	0.24	0.019	0.259

It is observed that the heat losses are within 0.4%. Therefore the above method is used for calculating the heat transfer coefficients.

4.2 Uncertainty Study

Uncertainty examination was carried out by the method suggested by Kline and McClintock. The parameters considered uncertainty analysis is listed below in table 2.

Table 2: Uncertainties of Important Factors for Air Jet Cooling.

SL. No.	Parameters	Uncertainty
1	Jet velocity	$\pm$ 1.0%
2	Discharge	$\pm$ 1.0%
3	Heat transfer coefficient, Q (ml/s)	$\pm$ 3.5%
4	Temperature difference between the test plate and nozzle exit.	$\pm$ 0.1^0C
5	Nusselt number	$\pm$ 3.5%
6	Heat flux	$\pm$ 1.0%
7	Reynolds number	$\pm$ 1.5%

5. RESULTS AND DISCUSSIONS

Figures 2 and 3 represent the vertical jets with the diameter of jet as 0.05 cm. The values of Reynolds number considered is in the range of 1,300 to 1,820 for Z = 1 and 2 cm, and it is presented in $\ln(Nu_{avg}/Re^{0.25})$ versus ln(q) heat flux. We are getting a linear relationship for all the datas obtained with different values of Reynolds number tested in both the heights of Z.

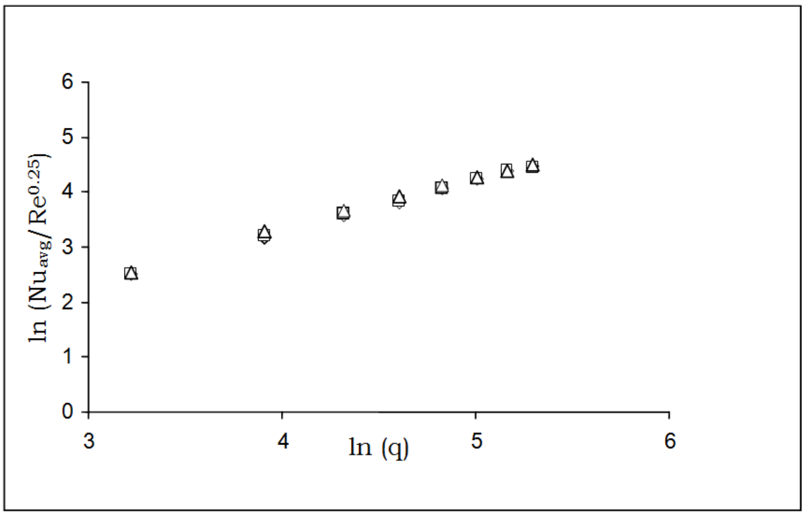

Figure 2: The Vertical Jet with Z = 1 cm and Jet Diameter of 0.05 cm for Different Values of Reynolds Number. Variation of $(Nu_{avg}/Re^{0.25})$ with Heat Flux.

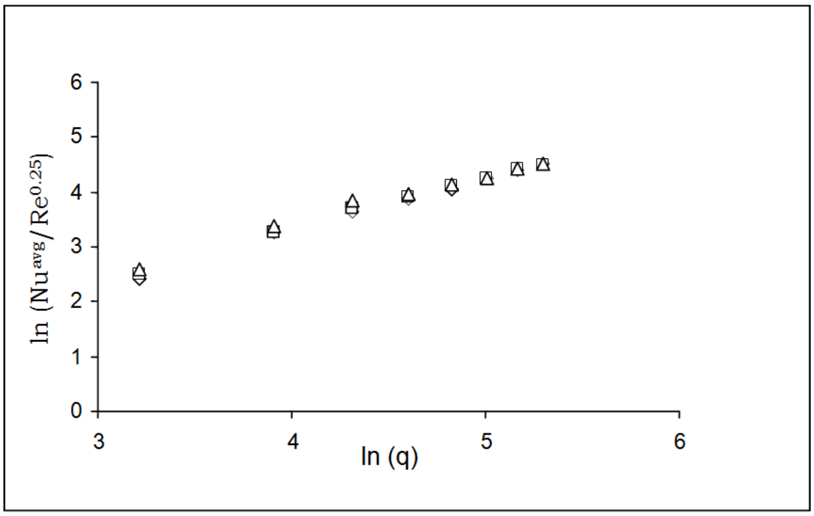

Figure 3: The Vertical Jet with Z = 2 cm and Jet Diameter of 0.05 cm for Different Values of Reynolds Number. Variation of $(Nu_{avg}/Re^{0.25})$ with Heat Flux.

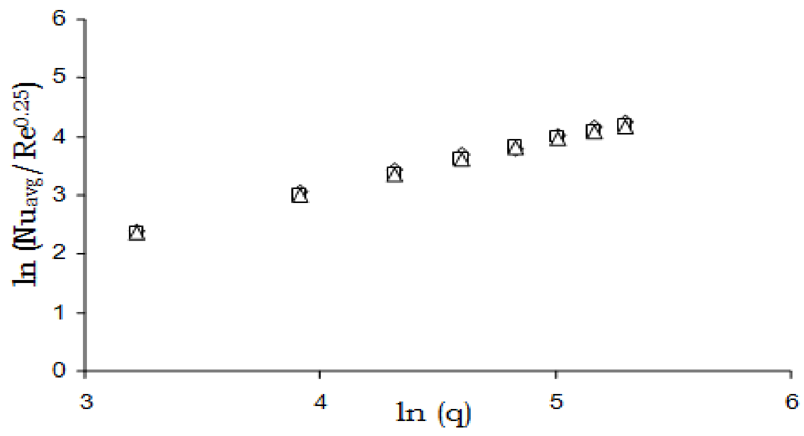

Figure 4: Vertical Jets with Z = 1 cm and Jet Diameter of 0.025 cm for Different Values of Reynolds Number.

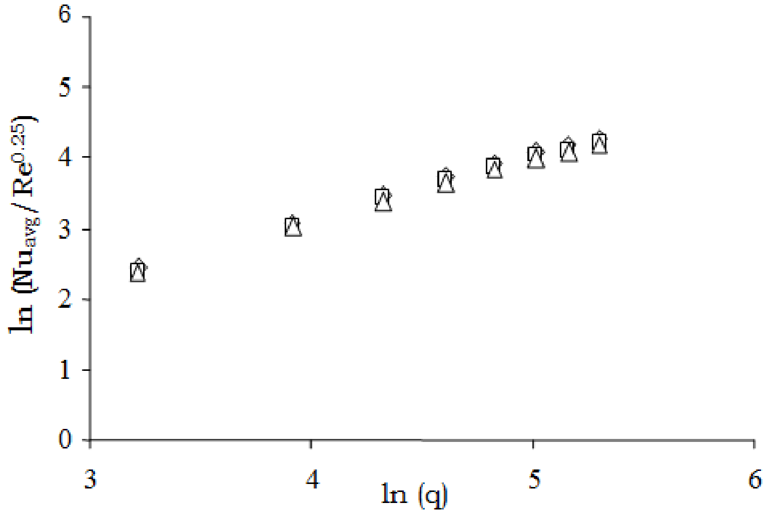

Figure 5: Vertical Jets with Z = 2 cm and Jet Diameter of 0.025 cm for different Values of Reynolds Number.

It is also observed in figures 4 and 5 that the same linear relationship is good for the diameter of jet 0.025 cm, though the range of Reynolds number are quite large due to the lesser diameter of jets considered in these investigations.

In figure 6, the values of Z is considered as 1 cm and 2 cm with Reynolds number values in the range of 1200 to 1900, the jet diameter of 0.05 cm for both horizontal and vertical jets. The mean data follows the below relationship.

$$Nu_{avg} = 0.75\ q^{0.9}\ Re^{0.25} \quad \textbf{(1)}$$

In figure 7, the values of Z considered is same as 1 cm and 2 cm, but the Reynolds number range is varied from 2500 to 4500 for a jet diameter of 0.025 cm. Here, also in case of 0.025 cm jet diameter, the average data follows the linear relationship similar to the above relationship (1) that is as given below.

$$Nu_{avg} = 0.69\ q^{0.8}\ Re^{0.25} \quad \textbf{(2)}$$

Different equations were obtained for jet diameter of 0.05 cm and 0.025 cm, but the functional association is same in both the cases. By assuming the Prandtl number as 0.7 for air, we are modifying the above equations 1 and 2 as below.

$$Nu_{avg} = 0.87q^{0.9}Re^{0.25}Pr^{0.4} \quad \text{for jet diameter of 0.05 cm} \quad \textbf{(3)}$$

$$Nu_{avg} = 0.80q^{0.8}Re^{0.25}Pr^{0.4} \quad \text{for jet diameter of 0.025 cm} \quad \textbf{(4)}$$

The influence of Reynolds number is less but the heat flux effect on the Nusselt number is noticeable. The equations obtained by introducing the Prandtl number is valid for a heat flux range of 200 W/cm^2, but the constants and exponents are quite different, but the functional relationship is valid for both the jets of diameter 0.025 cm and 0.05 cm.

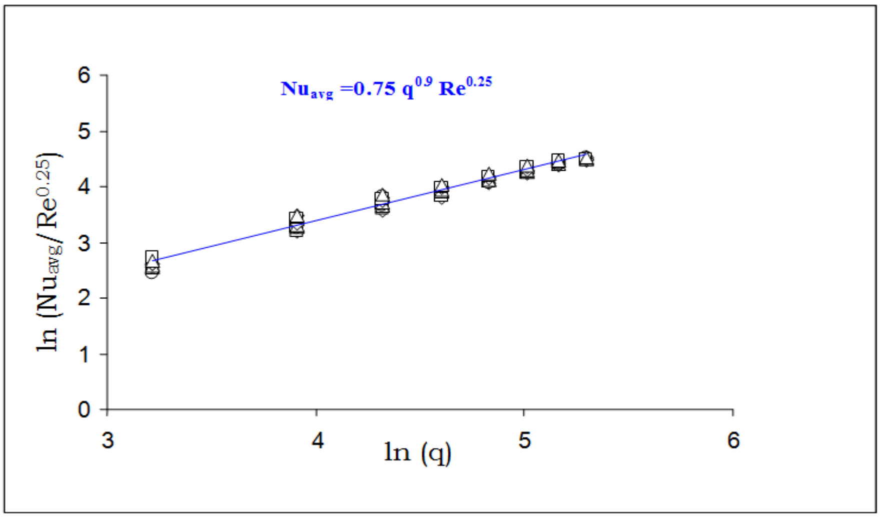

Figure 6: Combined results of Vertical and Horizontal Jets for Z = 1 cm and 2 cm for Jet Diameter of 0.05 cm.

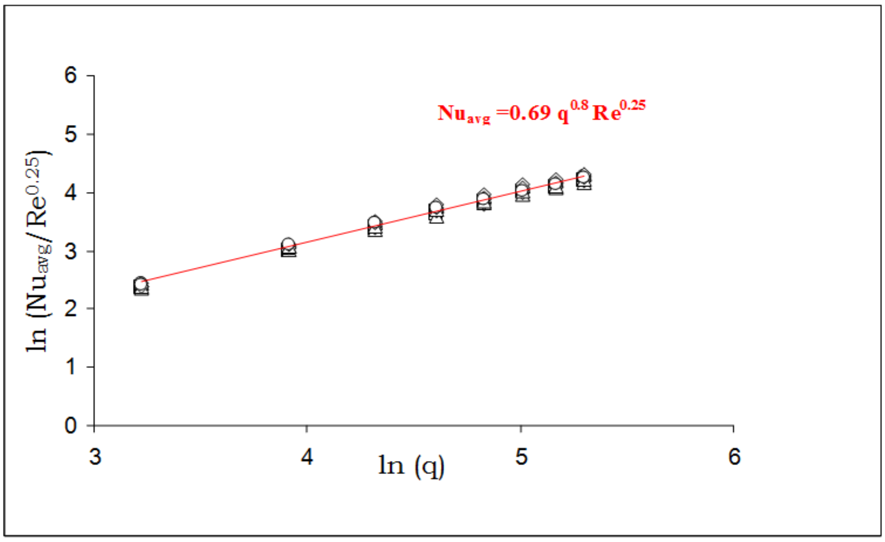

Figure 7: Combined Results of Vertical and Horizontal Jets for Z = 1 cm and 2 cm for Jet Diameter of 0.025 cm.

6. CONCLUSIONS

In this study, the test surface is 2 x 2 cm area, which is made up of copper material. The values of heat flux varied from 25 to 200 W/cm^2, which is a prerequisite for high density electronic apparatuses. We are keeping the temperature range within 70^0C for their heads and the pitch of 3 mm. Tests were conducted for both horizontal and vertical jets by varying the Reynolds number, heat flux and the height of test plate to jet exit.

The relationship developed in the present investigation is as follows: $Nu_{avg} = Aq^mRe^n$.

It is observed that the effect of jet diameter, Reynolds number and heat flux is significant, but the other parameters considered in this investigation, such as vertical jets or horizontal jets and the height of the jets are negligible.

Heat transfer is a complex phenomenon, especially in the circumstance of multiple air jet cooling, though the key findings from the present investigations are:

- Developing a relationship of $Nu_{avg} = Aq^{m}Re^{n}$.
- The heat flux effect on Nusselt number is significant.

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AUTHOR PROFILE

Dr. Niranjanmurthy, has total 23 yearsof experience in teaching, industry and research. Dr. Niranjanmurthy's research and educational efforts have focused on heat transfer, thermodynamics and fluid mechanics. He received his bachelor's degree in Mechanical Engineering and Masters degree in Heat power engineering and Ph.D in Heat Transfer. He has more than 30 publications in the national/international journals and conferences. He has authored 15 text books in the field of Mechanical engineering including Heat transfer and thermodynamics. Few text books are reference books in the Visweswaraya Technological University, Karnataka, India. In his research work related to the multiple jet impingement cooling he has developed a correlation relating the Nusseltnumber, Reynolds number and heat flux. The correlation developed in his research work can be effectively used to design multiple water and air jet cooling system for electronic components. He has worked on liquid jet impingement, high heat flux engineering and electronics thermal management.